Fermilab

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POWER CONSUMPTION FOR THE MAIN RING RAMP

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The average electrical power used by the main ring magnets for the accelerator cycle represented in Figure 1 is

$$P = \int_{T_1}^{T_8} I^2(t)\ R dt/(T_8 - T_1) \tag{1}$$

where I is the ramp current, R is the main ring resistance (~7.5Ω), and T_1 and T_8 are the start ramp and end ramp times respectively. The correspondence between the beam energy and the required magnet current is given to the few percent level by

$$I \approx 11.42 \times E \tag{2}$$

where E is the kinetic energy in GeV. However, in order to keep the calculations clean so that they can be used to good precision for the widest range of accelerator parameters, it is good to be a little more precise. The kinetic energy E is converted to momentum by

$$pc = \sqrt{E(E+2m_0c^2)} = \sqrt{E(E+1.876)} \quad \{\text{GeV}\} \tag{3}$$

The magnet rigidity Bρ is

$$B\rho = p/.0299725 \quad \{\text{kGm}\} \tag{4}$$

where ρ is 742m, the magnetic radius for the ring. Thus, for any specified energy the bending field is known. The corresponding current is taken from the excitation curve for the main ring magnets[1], Figure 2. Table I shows these quantities for a few typical momenta.

A little computer program has been written to make the average power calculation and give either the corresponding cycle time for a specified power level or the power corresponding to a given cycle time. In the hope of increasing the general usefulness of this program, it has been written to accept the ramp parameters in three different forms:

1) E1, E2, DT1, DT2, DT3, S1, S2, S3 (linear approximation)

2) parameters of M. R. X530 p17 (parabolas included)

3) E1, E2, T2, T3, T4, T5, T6, T7 (linear approximation)

A properly chosen linear approximation is quite adequate for power calculations to a few percent accuracy, particularly if simply the change in average power is calculated as a ratio of the approximated power to the same approximation for a measured case. Also to explore the general dependence of power on basic parameters such as rate of rise, the linear approximations are convenient and adequate. The process of choosing the correct linear approximation to closely predict real cases is somewhat difficult, however, and for accurate absolute results, it is necessary to include the parabolas, mid-ramp break points, etc.

The greatest uncertainty in the power calculations is the value of the main ring resistance R in Eq. 1. Unpredictable changes from day-to-day may occur in feeder temperatures, LCW temperatures, SCR power losses, etc. It is partly with the hope of pinning down some of this variability that these calculations have been carried out with some attention to small effects. One can imagine, for instance, that there is enough fluctuation in temperature during the cycle that R becomes noticeably dependent on the average or instantaneous power. The dynamic resistance term in the main ring power program[2]

$$R(I) = R_0(1.+I^2R_1) \tag{5}$$

where $R_1 \approx 4\times10^{-8}A^{-2}$ is not really a term of this type because it accounts for voltage drop to the power supplies under load. There could be, however, a small effect in the true resistance of similar form, which must be included to make the calculation good to ~1% over a wide range of ramp parameters. For the purposes of the following graphs, the value of R has been taken as a constant ($R = 7.516\ \Omega$) found by normalizing to 45 MW for a 9 second 400 GeV ramp with a one second flattop given by the p17 parameters in Table II.[3] These plots based on a linear approximation to the ramp are good to ~5% level.

Figure 3 gives the relation between average power and cycle time for 200, 300, and 400 GeV with a one second flattop. Figure 4 gives the power versus flattop length for a 10 second cycle at 200, 300, and 400 GeV. Figure 5 plots on the x-axis is the cycle time required for 100, 200, and 300 GeV front porches of the length given on the y-axis for a 400 GeV, one second flattop ramp with 45 MW average power allowed. Figure 6 plots the average power for a 10 second cycle with a one second flattop as function of flattop energy. In all of these examples, a constant rate of rise of 140 GeV/sec and an invert slope of 350 GeV/sec have been used.

Figure 7 is calculated using the actual 400 GeV ramp parameters and the average power measured between 0400 and 0800, April 27, 1976. During this period, the cycle time was 10.47 sec. and the ramp average power was 43.5 MW. The figure gives the linear relation between flattop length and cycle length for 400 GeV at an average power of 45 MW.

1) The particular data used is for the B-2 magnets used in the E-69A spectrometer, J. MacLachlan, 1973, unpublished.

2) The new main ring power supply program is the work of R. Cassel, R. Flora, and H. Pfeffer.

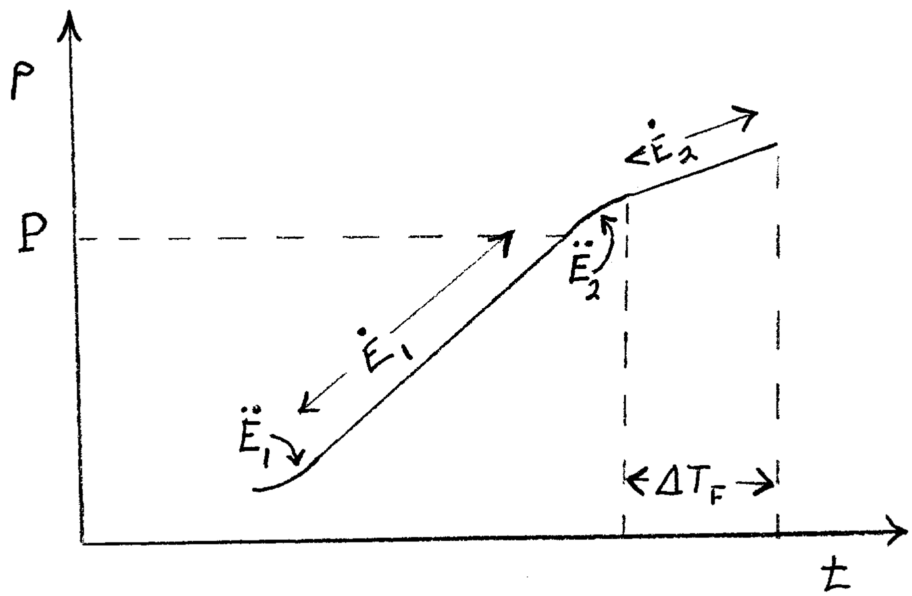
3) F. Turkot, private communication

TABLE I: Main Ring Excitation

E {GeV}	p {GeV/c}	Bρ {kGm}	B {kG}	I {kA}
8	8.889	296.6	.400	.102
20	20.917	697.9	.941	.239
100	100.934	3367.5	4.538	1.153
200	200.936	6704.	9.035	2.299
300	300.937	10040.	13.352	3.447
400	400.937	13337.	12.028	4.696
500	500.937	16713.	22.525	6.880

TABLE II: Ramp Parameters Including Parabolas

p {GeV/c}	ΔT_F {sec}	$\dot{E}_1$ {GeV/s}	$\ddot{E}_1$	$\ddot{E}_2$	$\dot{E}_2$
8.9	2.08	0.	0.	0.	0.
30.	0.	100.	400.	0.	100.
375.	0.	150.	50.	-200.	120.
399.5	1.	100.	-1000.	-500.	0.
200.	0.	-400.	-3000.	500.	-350.
20.	0.	-300.	200.	500.	- 70.
9.9	.05	- 70.	0.	300.	0.
8.9	1.0	- 10.	- 500.	100.	0.



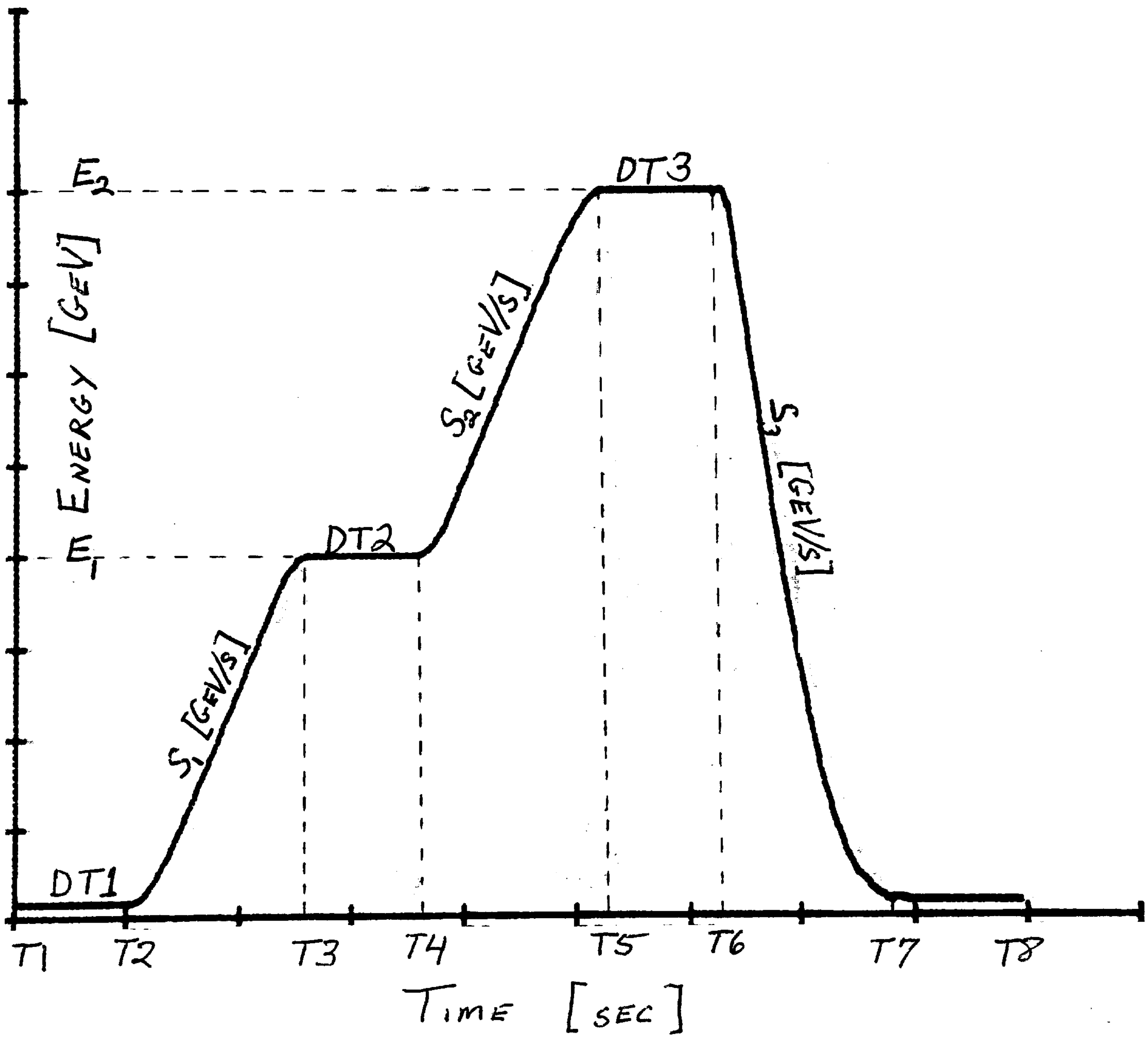


FIGURE 1: MAIN RING RAMP

EXCITATION CURVE FOR B-2 MAGNET

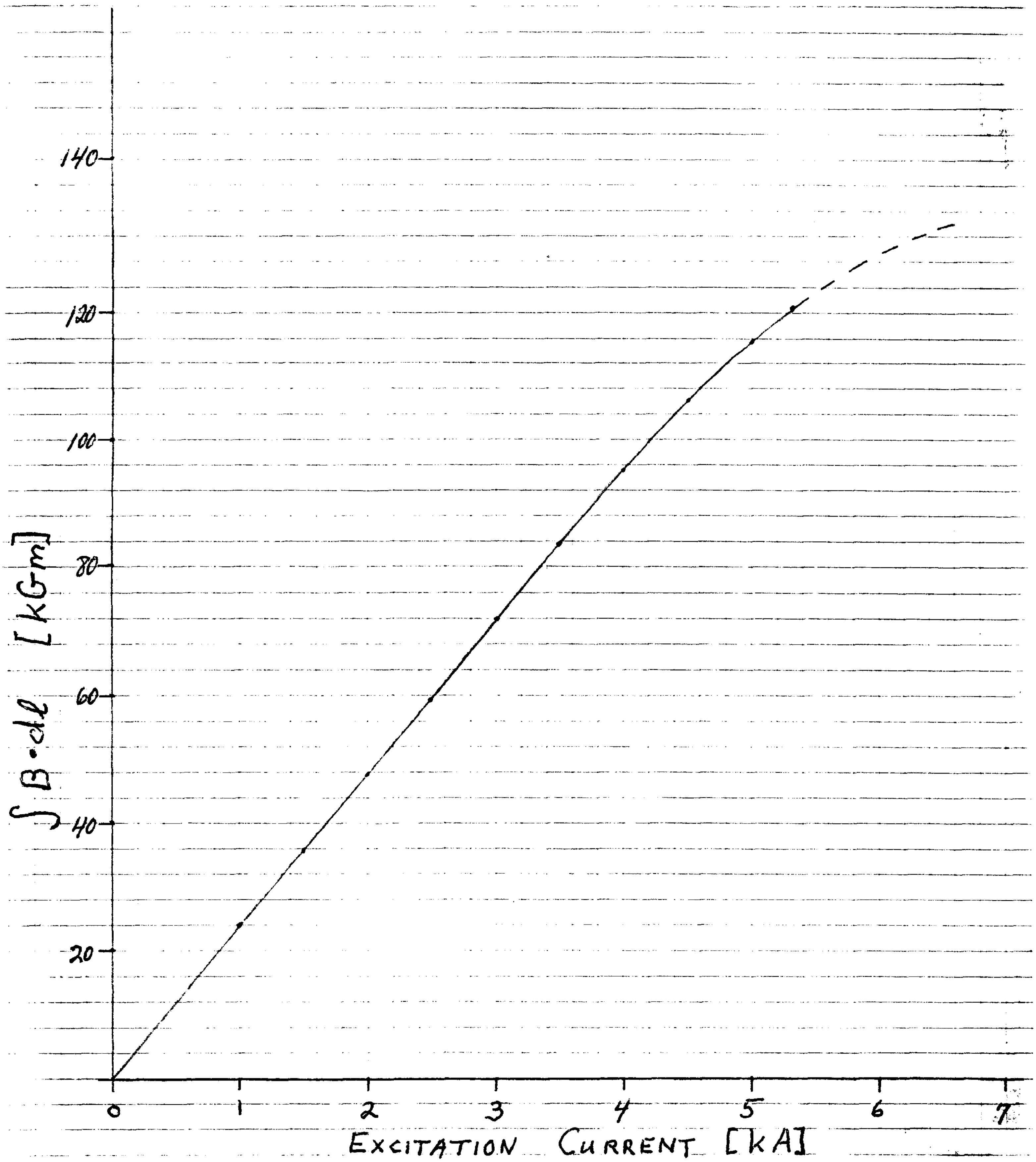


FIGURE 2

AVERAGE POWER VS. CYCLE LENGTH FOR 1 SEC. FLATTOP

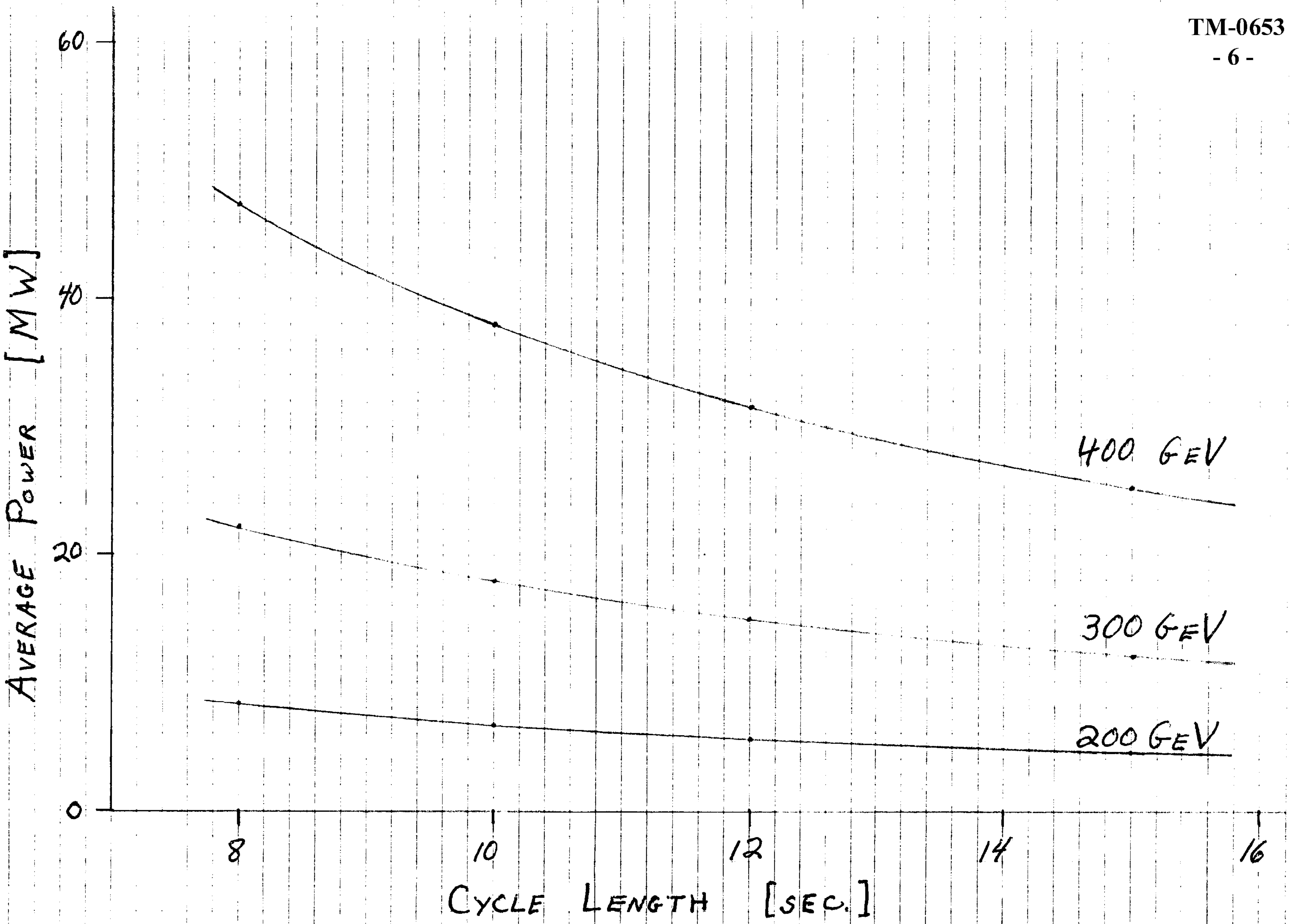


FIGURE 3

AVERAGE POWER VS FLATTOP LENGTH — 10 SEC CYCLE

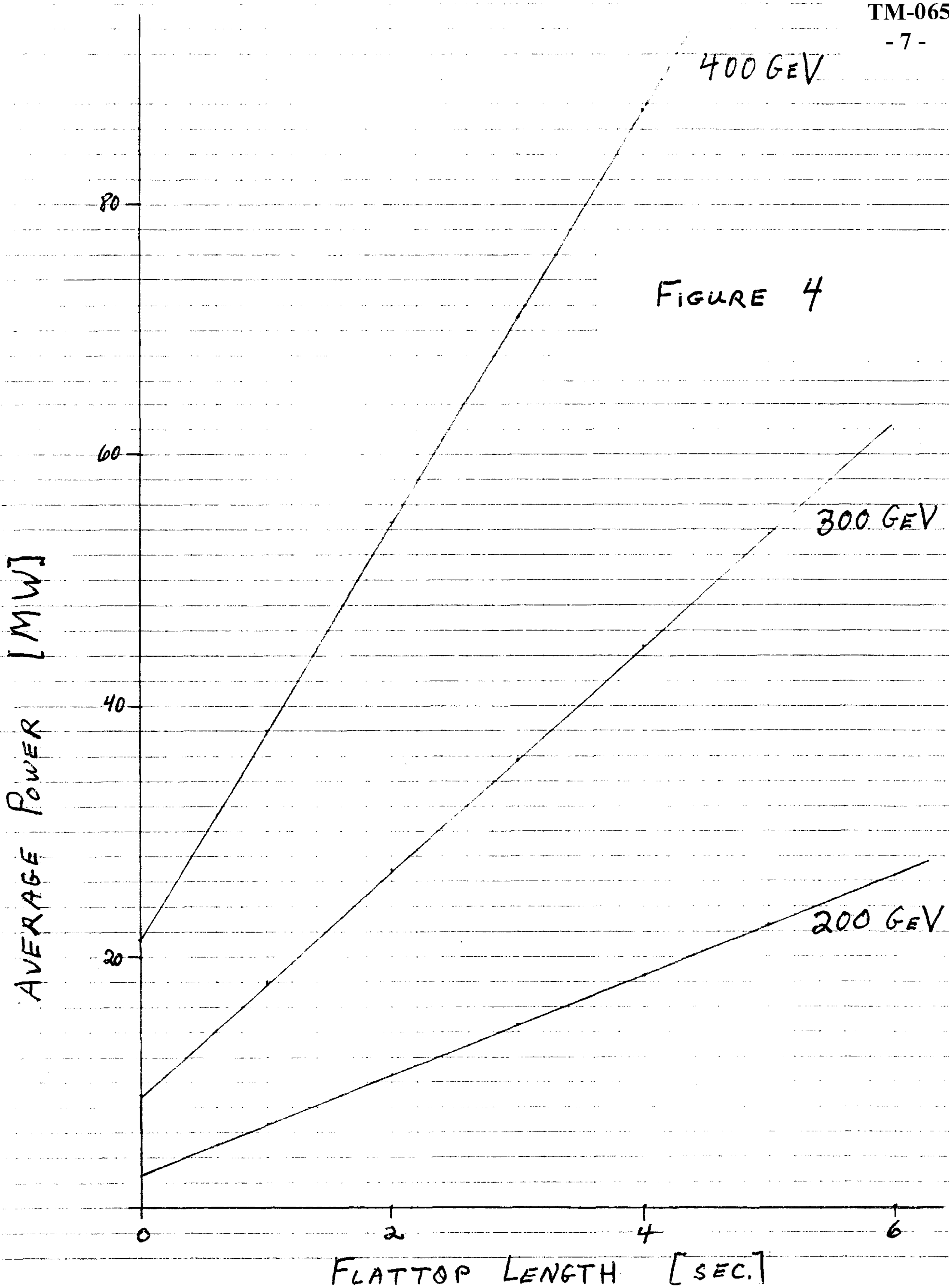


FIGURE 4

FRONT PORCH LENGTH VS CYCLE TIME AT 45 MW AVERAGE POWER AND 400 GEV 1 SEC. FLATTOP

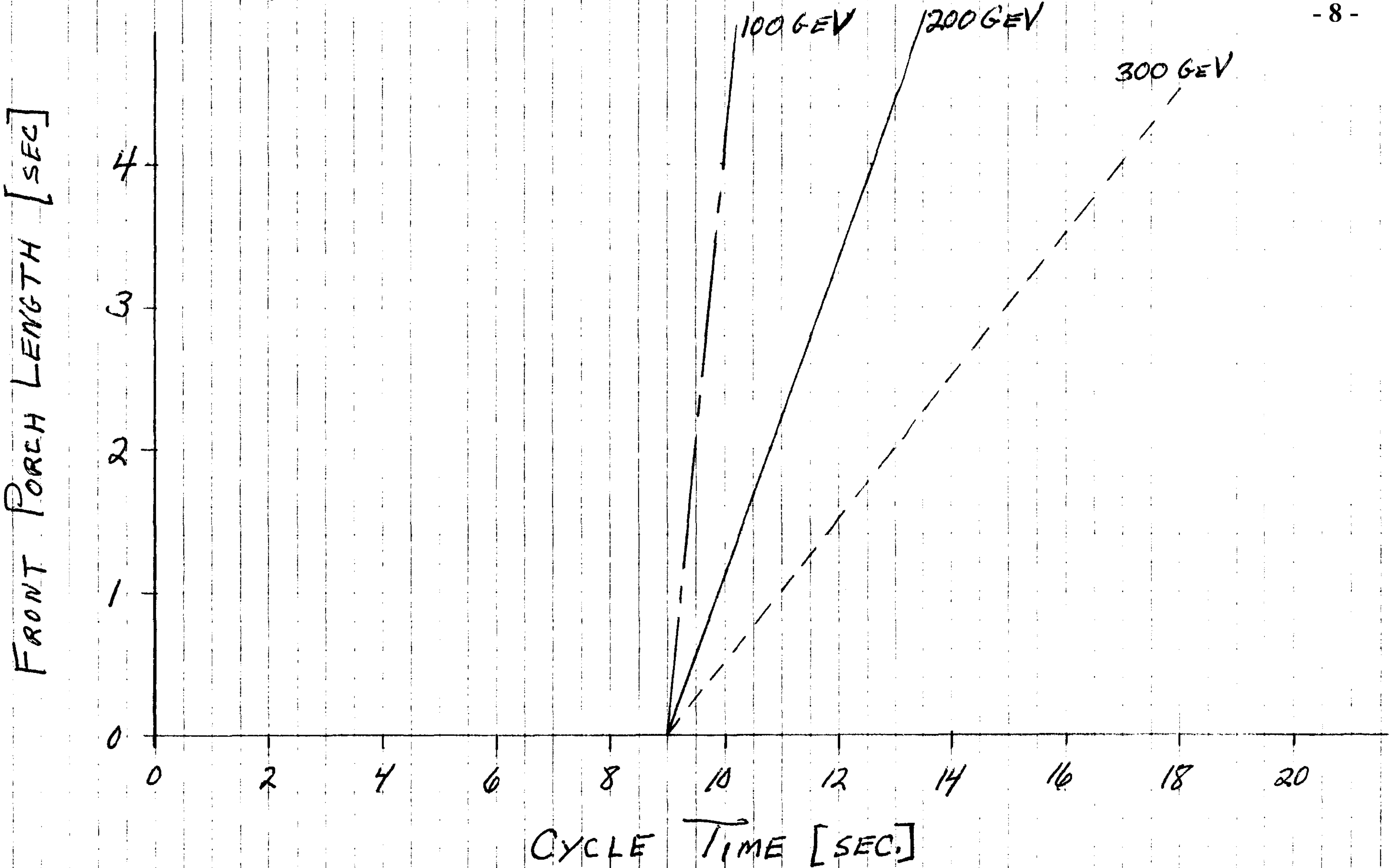


FIGURE 5

AVERAGE POWER VS FLATTOP ENERGY FOR 10 SEC. CYCLE

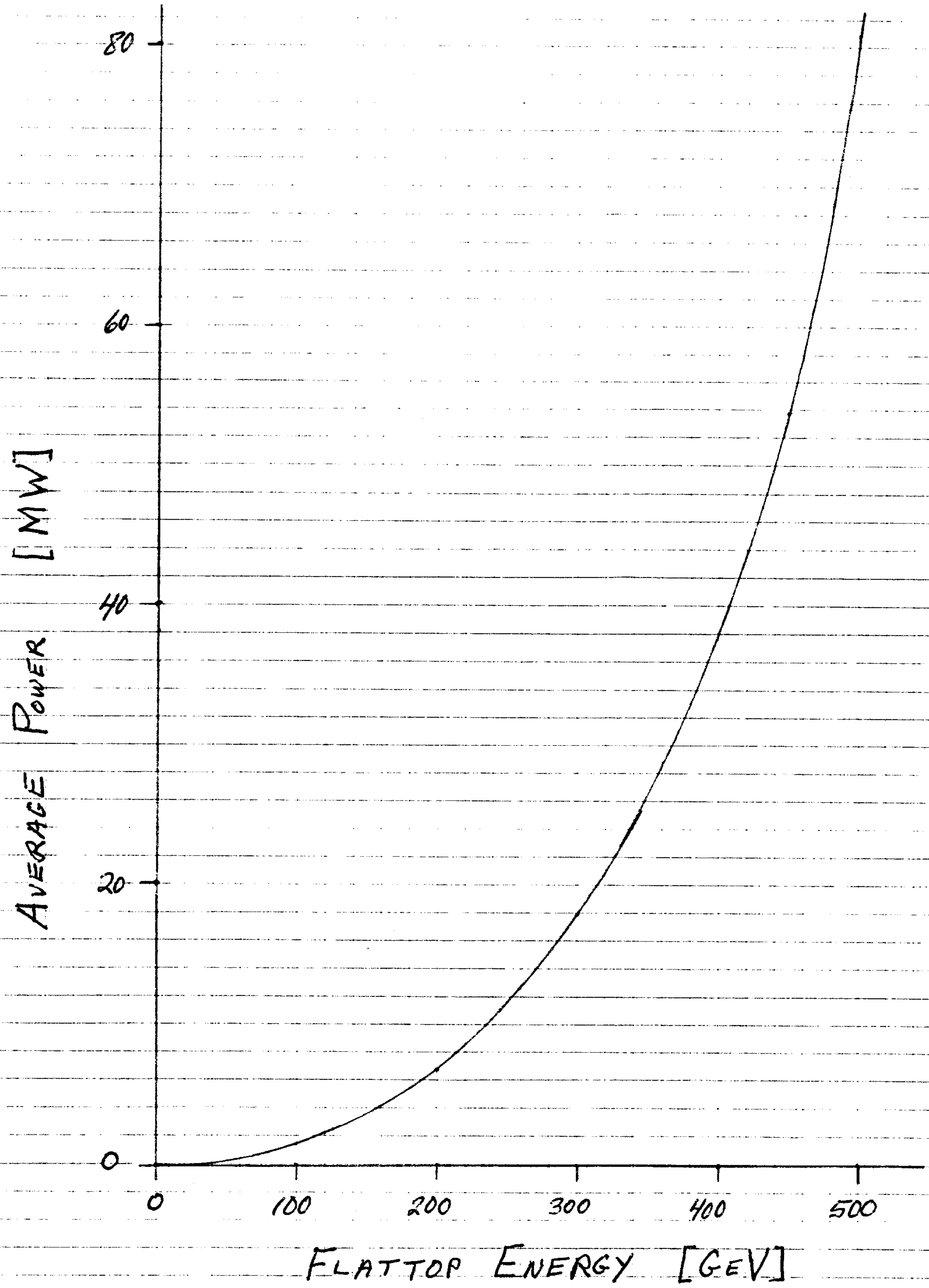


FIGURE 6

FLATTOP LENGTH VS CYCLE LENGTH AT 45 MW

(BASED ON MR RAMP PARAM OF 4/26 & MEASURED PL

400 GeV, 1 SEC FLATTOP

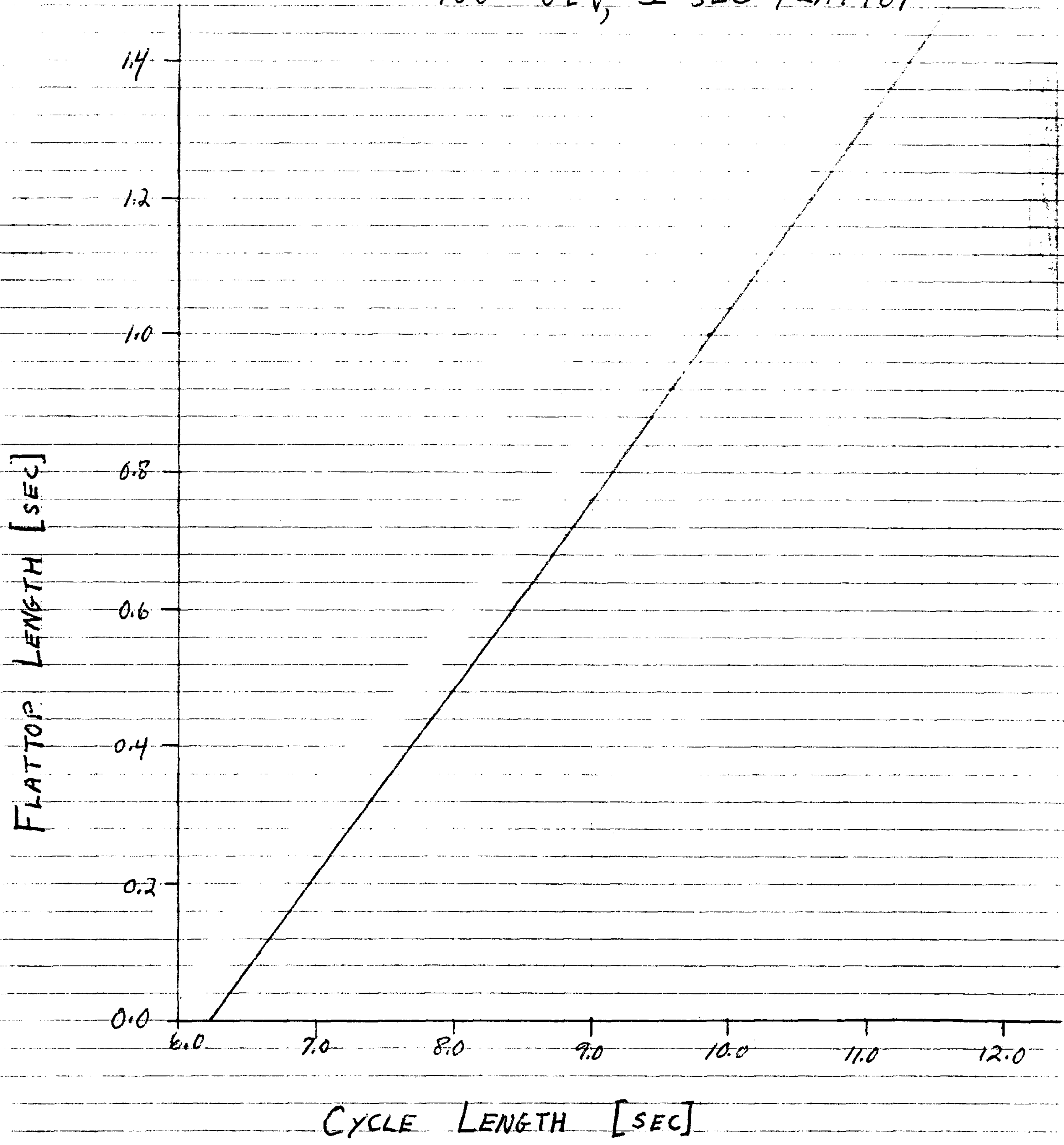


FIGURE 7